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The Development of NDE Techniques for Payload Fairings and Other Composite Structures

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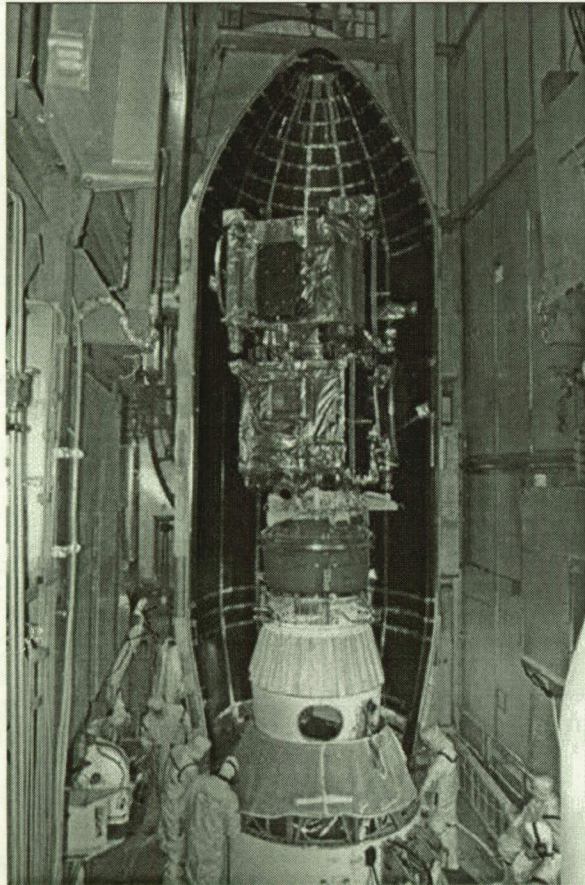
Kennedy Space Center

Objective



- Develop and demonstrate NDE techniques to assist in the fabrication and operational monitoring of expendable vehicle payload fairings and other composite structures.
 - Delta II fairing contains Rohacell foam core which enhances moisture uptake and thereby weakening.
 - Constellation is designing a variety of composite structures for Orion, Ares 1 and Ares V which will require NDE techniques.

Moisture in Delta II Fairing



STEREO on the Delta II booster with fairing.

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- Problem Statement
- After manufacturing, the fairing structure is exposed to a varied environment which results in moisture exposure and diffusive absorption.
- The effect of moisture is to weaken the structure especially when the fairing is heated during ascent. This weakening increases the risk of structural failure under ascent loads.
- ULA uses a proprietary computer model WetLam to estimate moisture content in fairing at launch.

Two Paths Pursued - Measurement and Modeling



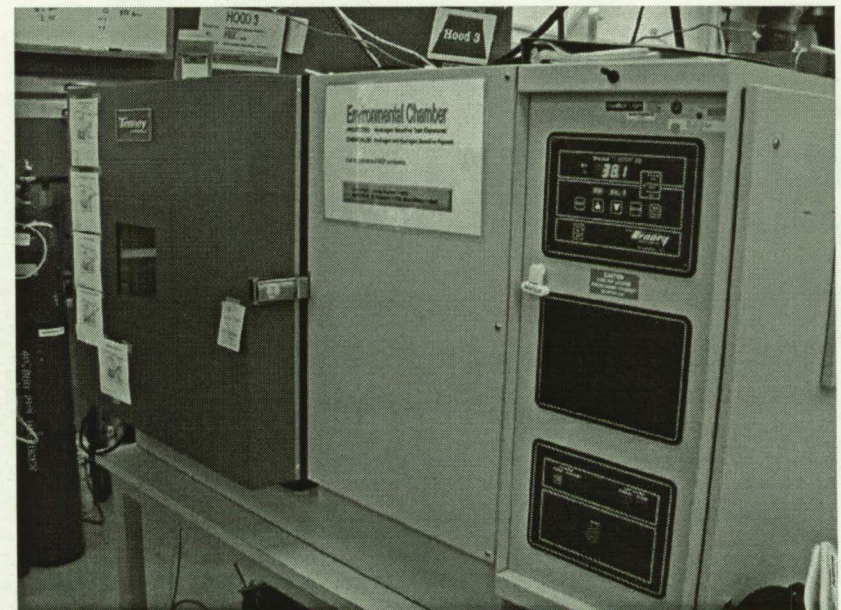
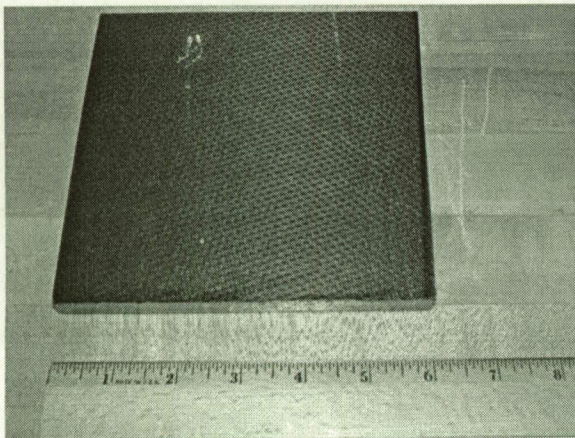
Measurement

- We reviewed several promising methods:
- Gravimetric approach (2004)
 - A witness sample follows the fairing and is weighed periodically to determine moisture uptake
- Neutron scattering
 - Vendors believe that carbon atoms will provide a strong signal, making it difficult to distinguish from water.
 - This is likely to require expensive development.
- Capacitance/ Impedance
 - Preliminary tests showed some promise but revealed challenges of calibration, repeatability, and sensor placement.
 - The method turned out to be less practical than originally thought:
 - The GEC faces are not electrically isolated from one another in an actual fairing, unlike our test samples.
 - While an embedded conductor in the foam core could make a capacitance measurement possible, it would require much more extensive analysis to determine impacts on the structural integrity and the manufacturing process.

Modeling



- Dried samples were inserted into an environmental chamber (fixed temperature and RH) and the mass was recorded versus time;
 - Rohacell foam core material of two different densities
 - A GEC facesheet with the glue still present on one side
 - A cutout from a fairing section was used with aluminum tape on the edges.
- The diffusivity was computed for each of the individual pieces.
- A multi-layer predictive model was developed based on finite difference methods.
- The model prediction and the data from the cutout were compared.
- A foam sample was vacuum dried at room temperature to determine the temperature dependence of the diffusivity.



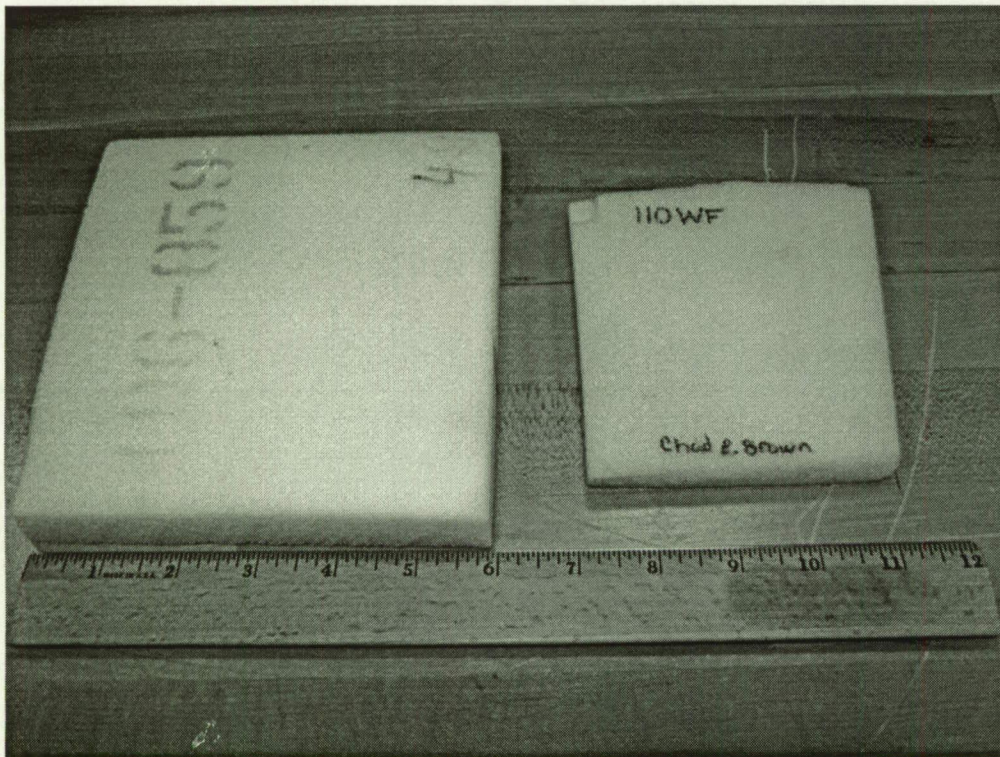
Rohacell Foam Core Diffusivity



Rohacell samples of different densities were tested (0.125 g/cc and 0.107 g/cc (110 WF)).

The environmental chamber set points were 37.8°C & 85.0% RH.

The data was fit to the following equations in Springer (p16) to find D_x



diffusivity correction for open sides:

$$D_x = D \left(1 + \frac{h}{l} + \frac{h}{w} \right)^{-2}$$

D - uncorrected diffusivity

h - thickness of sample in cm

l - length of sample in cm

w - width of sample in cm

$$G = \frac{M - M_i}{M_m - M_i} = 1 - \frac{8}{\pi^2} \sum_{j=0}^{\infty} \frac{\text{Exp}[-(2j+1)^2 \pi^2 (D_x t / h^2)]}{(2j+1)^2}$$

M - measured mass in g

M_i - initial mass in g

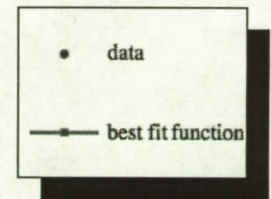
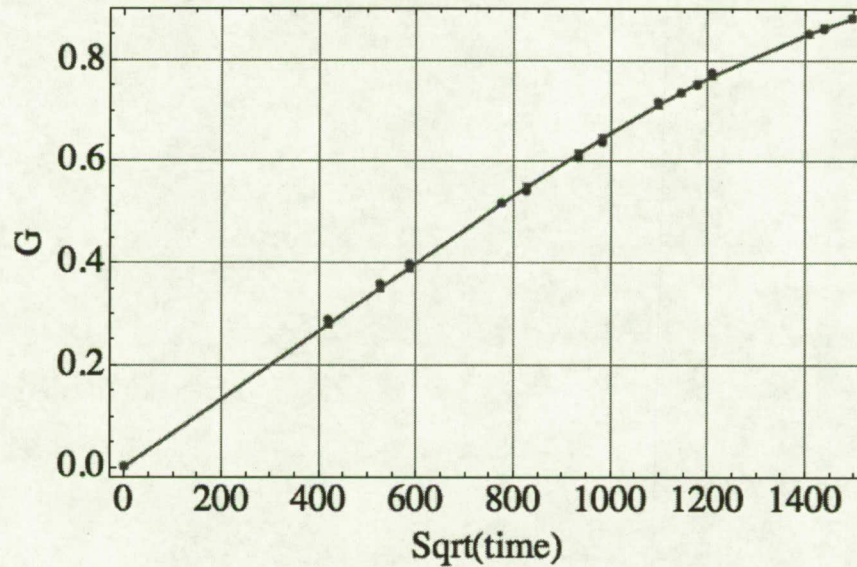
M_m - maximum mass in g

t - time in sec

Rohacell Foam Diffusivity

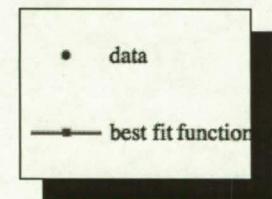
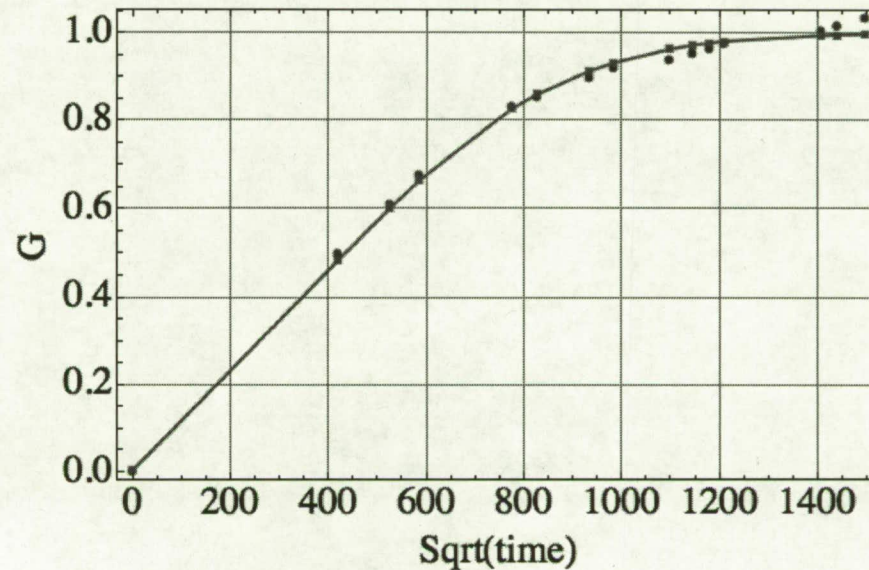


$D_x = 2.0 \times 10^{-7} \text{ cm}^2/\text{sec}$
(thicker specimen)



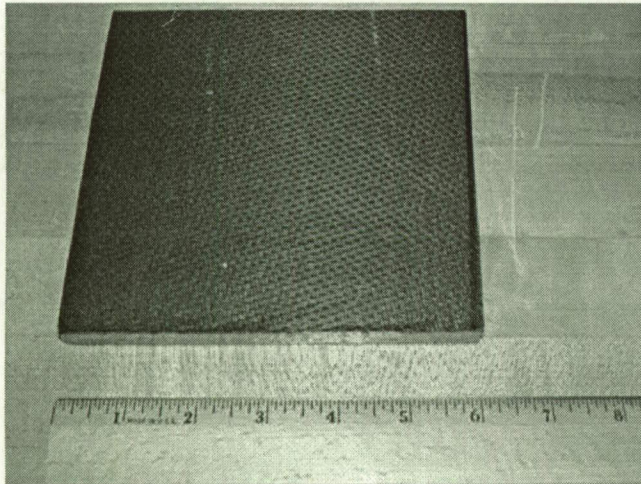
Delta II fairing core material
(110 WF)

$D_x = 2.8 \times 10^{-7} \text{ cm}^2/\text{sec}$

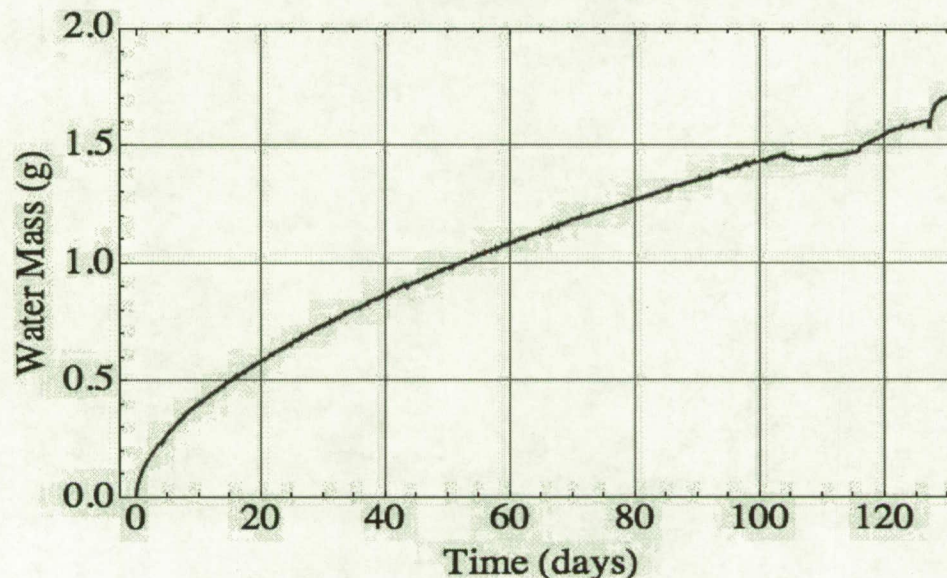


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Delta II Fairing Material Moisture Uptake



A sample of Fairing was dried and placed in an environmental chamber set at 37.8°C & 85.0% RH for approximately 130 days. The resulting change in mass plot versus time is shown below on the right.



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Moisture Uptake Computer Model



- We created an independent multi-layer moisture diffusion model based on finite-difference methods to compare with Wetlam (the ULA model)
- Our model assumes:
 - fixed temperature
 - fixed RH at outer boundaries
 - diffusion constant from ULA for GEC face sheet
 - KSC diffusion constant for the foam core
 - a and b parameters from ULA ($c=a*\phi^b$)
 - no glue layer
- The values that were used to model the Delta II fairing material appear in the table below:

	Density (g/cc)	a	b	D (cm ² /sec)	Area (cm ²)	h (cm)
facesheet	1.61	1.45	1.65	$2.0*10^{-9}$	248	0.142
core	0.111	10.6	1.9	$2.8*10^{-7}$	248	1.27

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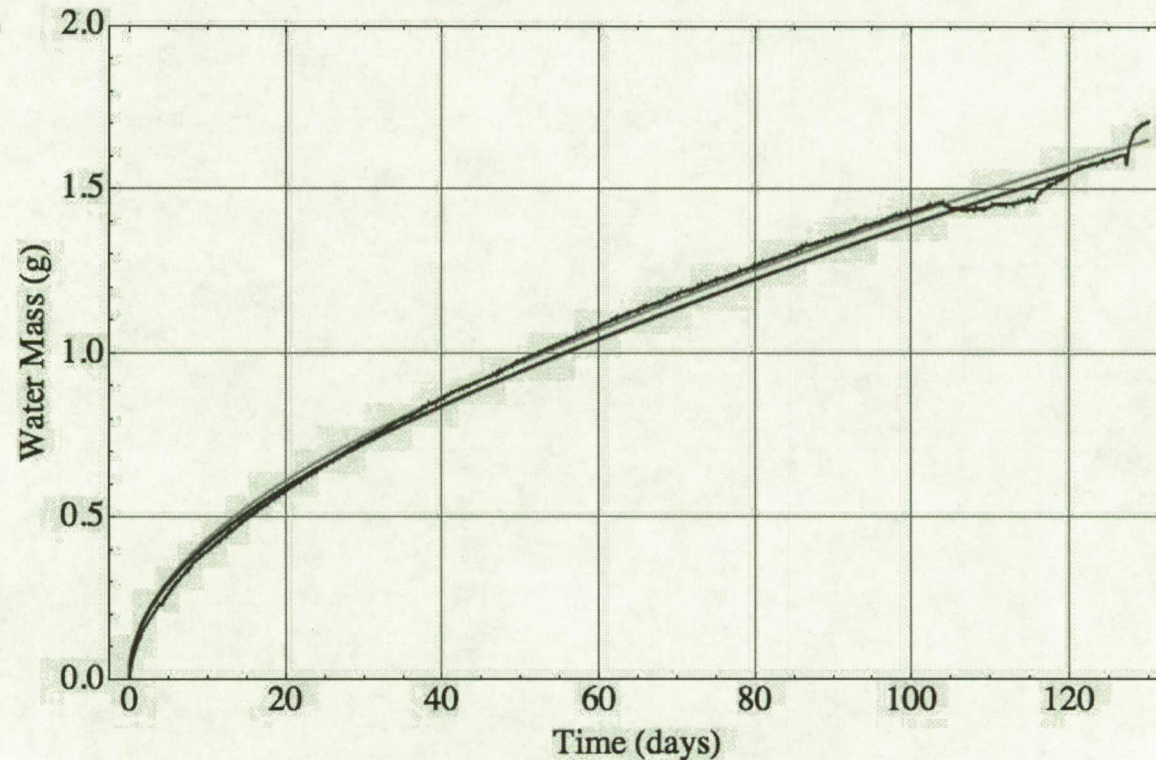
Data vs. Models



- Our model agreed with the output of Wetlam to within rounding errors and to the data.

ULA model in
green;

KSC model in
red



Delta II Results and Status



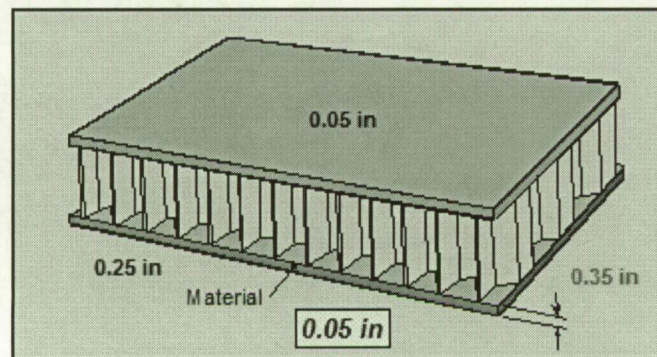
- We provided an independent verification of ULA's modeling approach to estimated moisture at launch.
- ULA has agreed to test gravimetric coupons from next fabricated fairing against model.



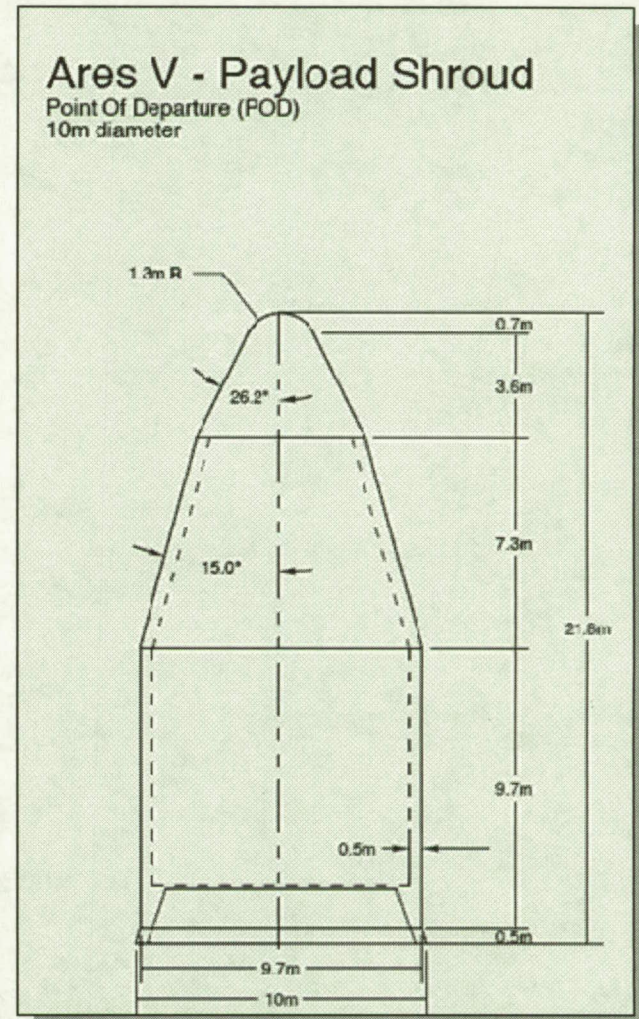
Ares V Payload Shroud



- Honeycomb Sandwich construction
 - IM7/977-2 face sheets
 - $[0/+45/-45/90]_s$ Quasi-Isotropic layup
 - Smeared into Equivalent Orthotropic properties
 - Only sized by total thickness – no layup optimization
 - Aluminum (Hexcel Al 5052) honeycomb core
 - 4 designs considered
 - including 4 wall thickness and two cell sizes
- Single “Access” petal with all penetrations
- Three non-penetrated petals
- Ring Frames at each angle change & base
- Simple analysis showed only a small effect from mid-panel rings; left for later trade.



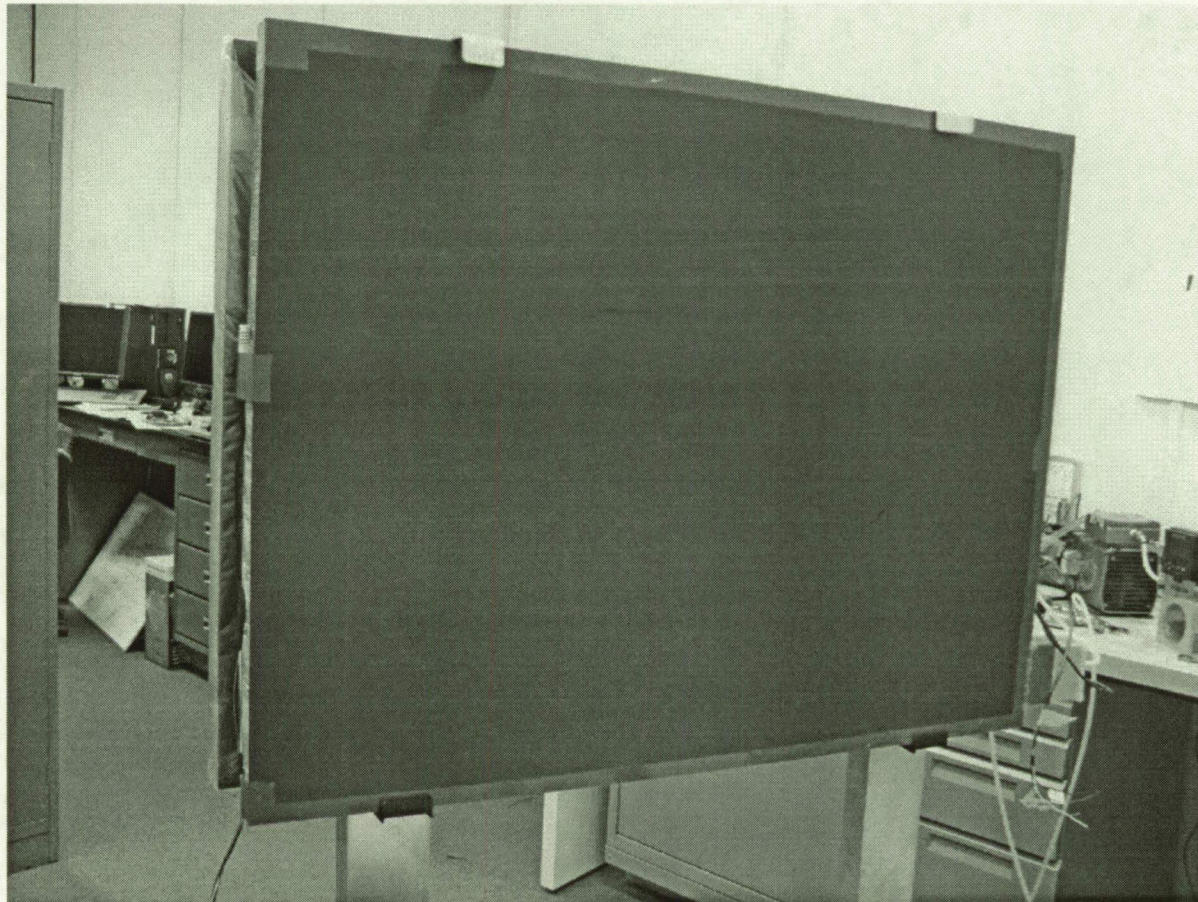
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ATK Fairing Samples

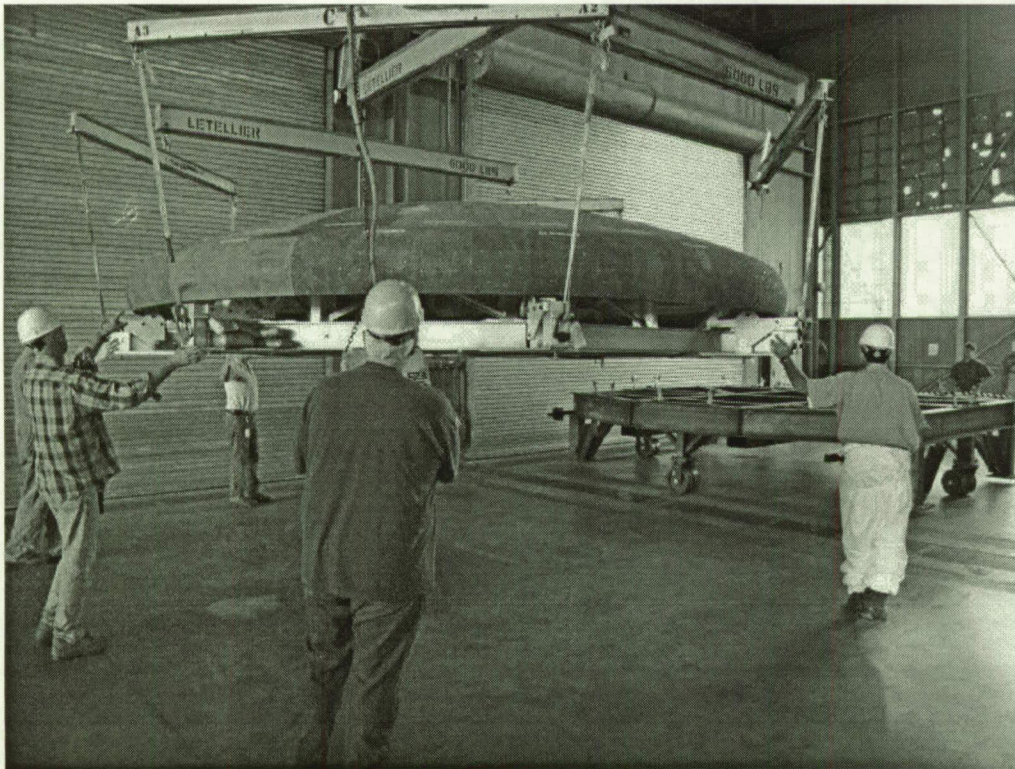


- We have begun testing a novel method to reduce moisture in perforated honeycomb sandwich structures.



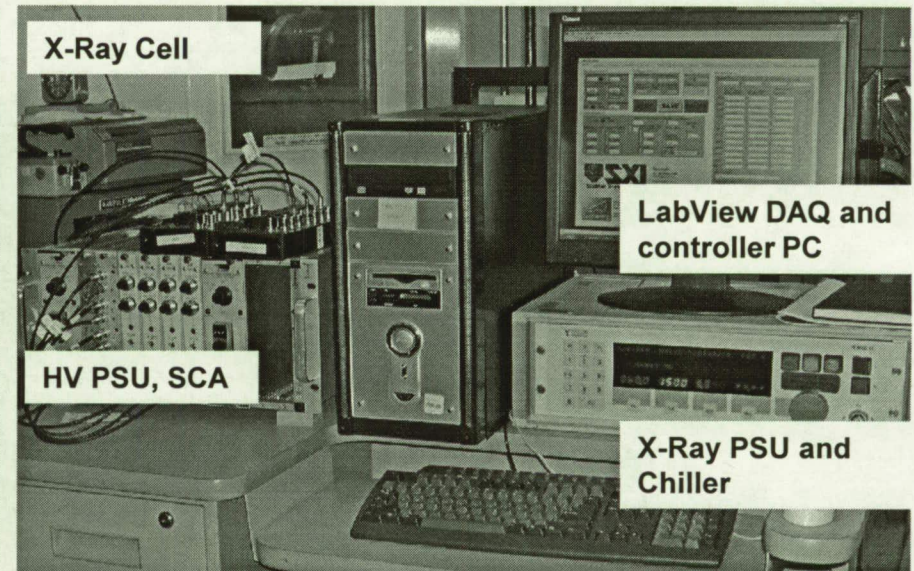
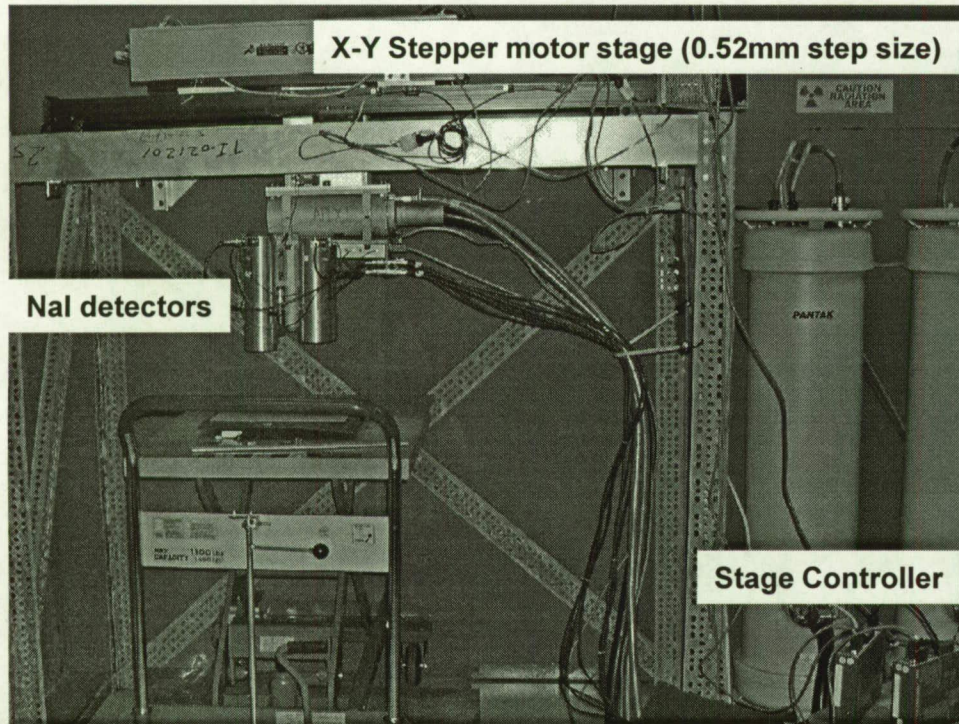
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Orion Heat Shield

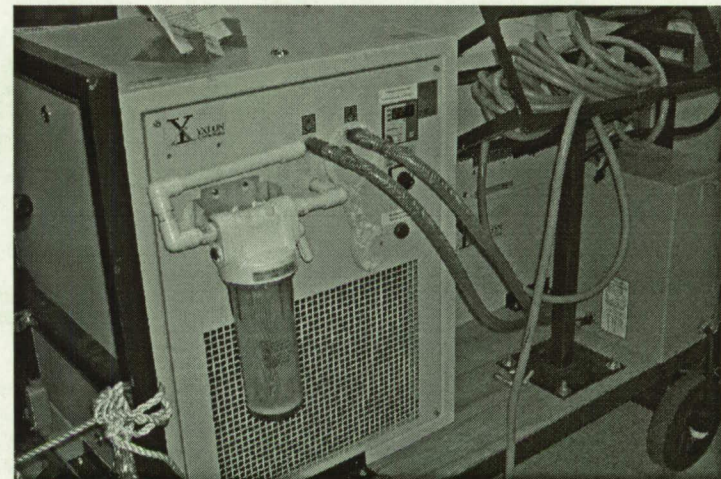


KSC has prototype LM heat shield with PICA tiles adhered to base-plate with RTV for evaluation of handling and NDE techniques and related NDE samples.

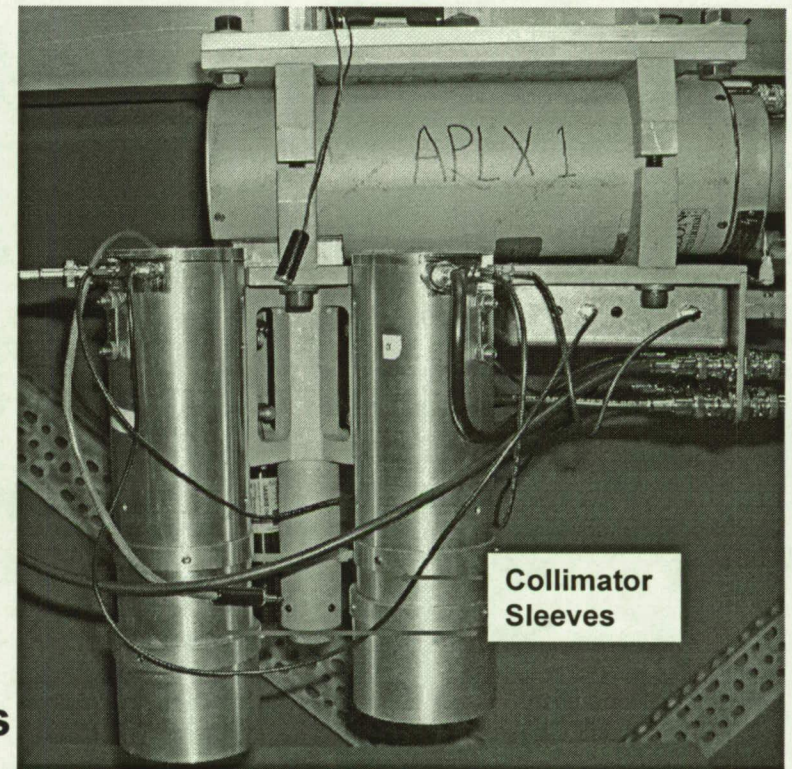
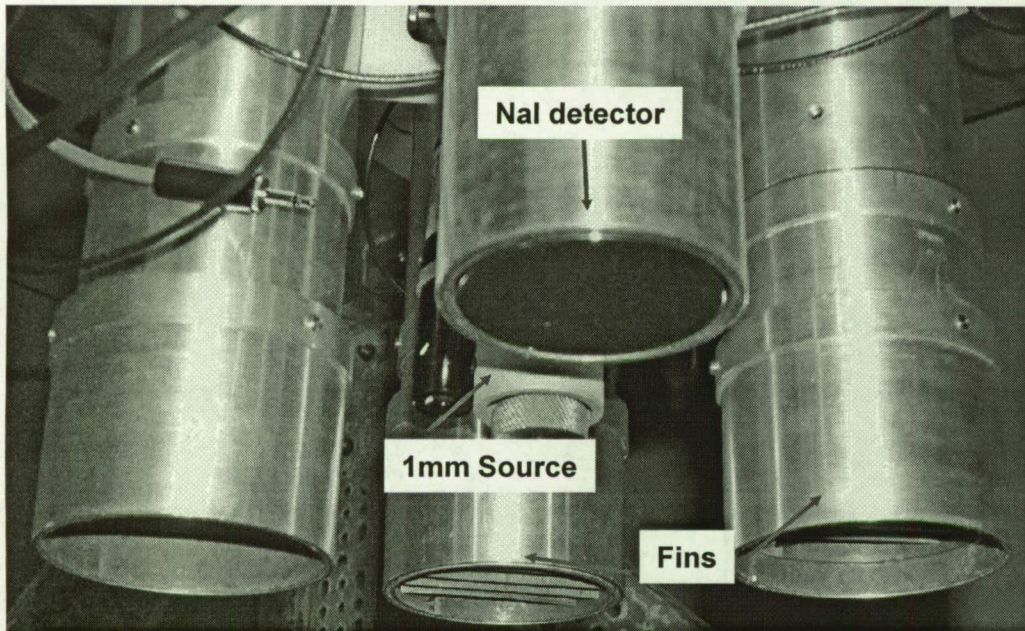
Backscatter X-Ray System



- Yxlon x-ray source
- Maximum settings 110kV 20mA
- Four Nal detectors
- 5.5mm spot size
- LabView stage control and DAQ

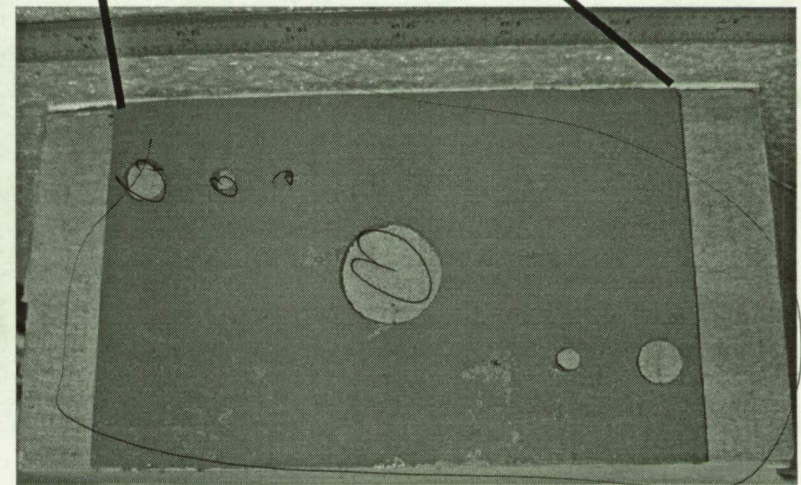
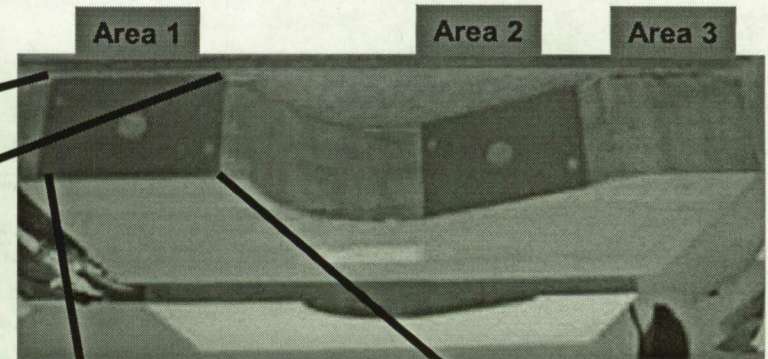
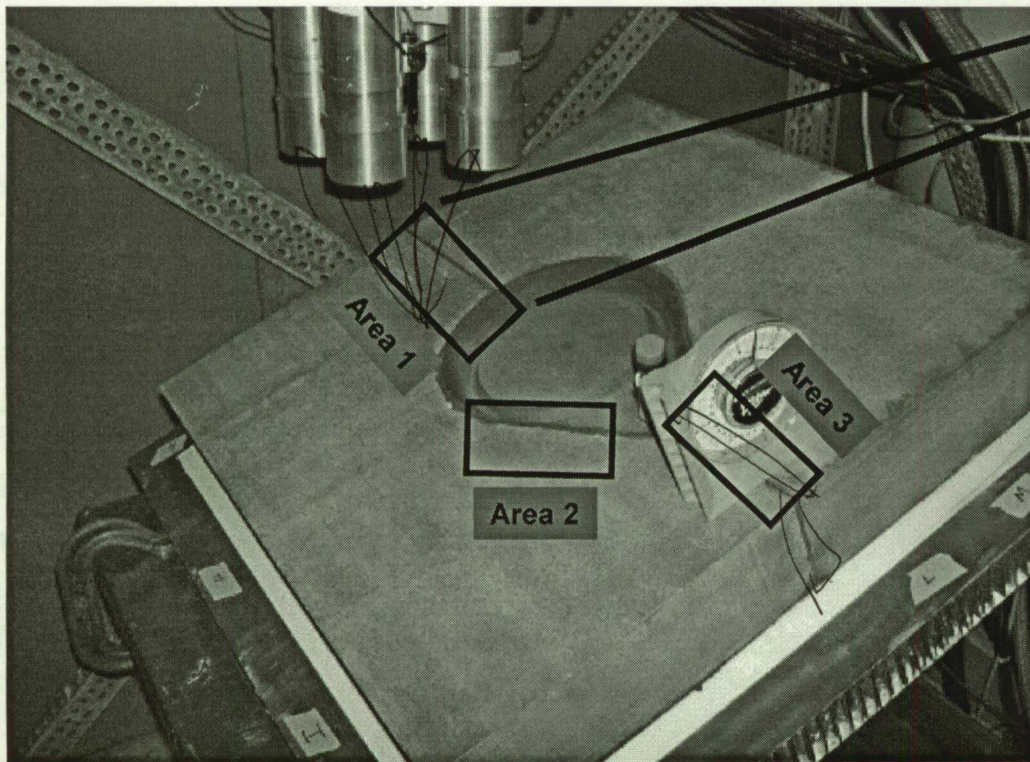


Backscatter X-Ray Head

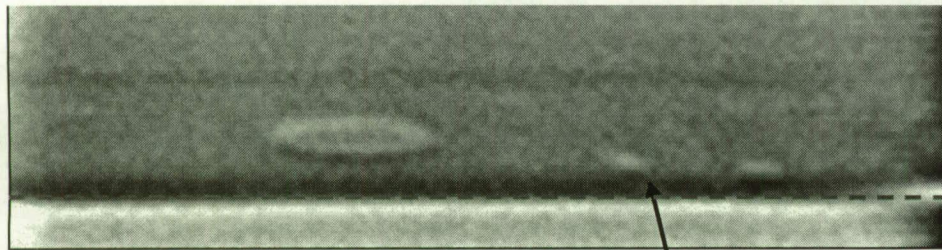


- Spot size focused to 1mm with lead apertures
- Collimator sleeves have 60mm travel length
- Lead fins are inside collimator sleeves and can be rotated to block out primary backscatter x-ray signals
- The Source and the detectors raster across the imaging area of interest

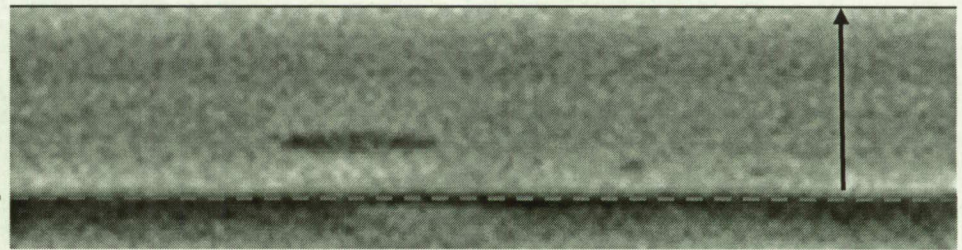
LDDU Regions of Interest



LDDU BSX Scan 11° Tilt



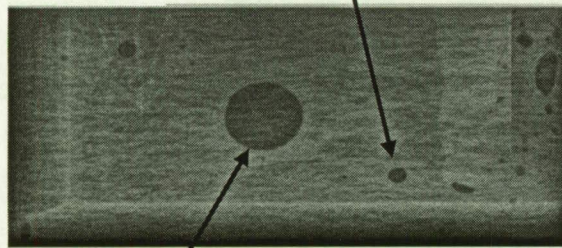
Detector 1



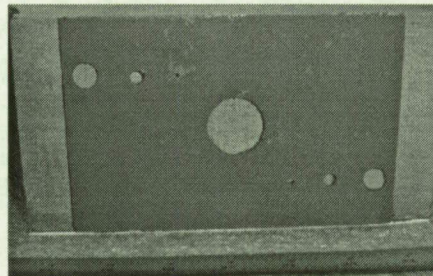
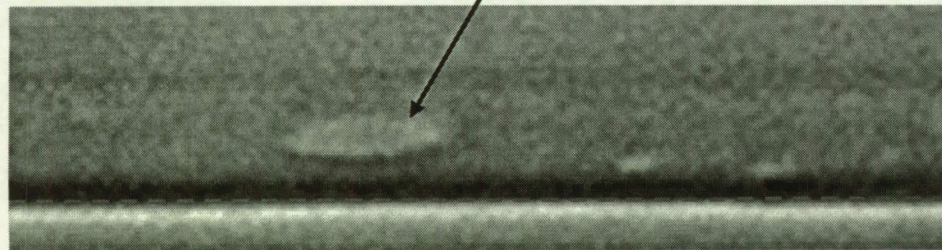
Detector 2

RTV/TPS interface

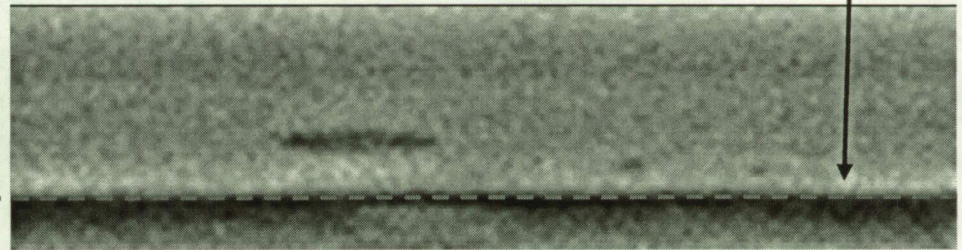
LDDU Surface



Detector 4



Detector 3

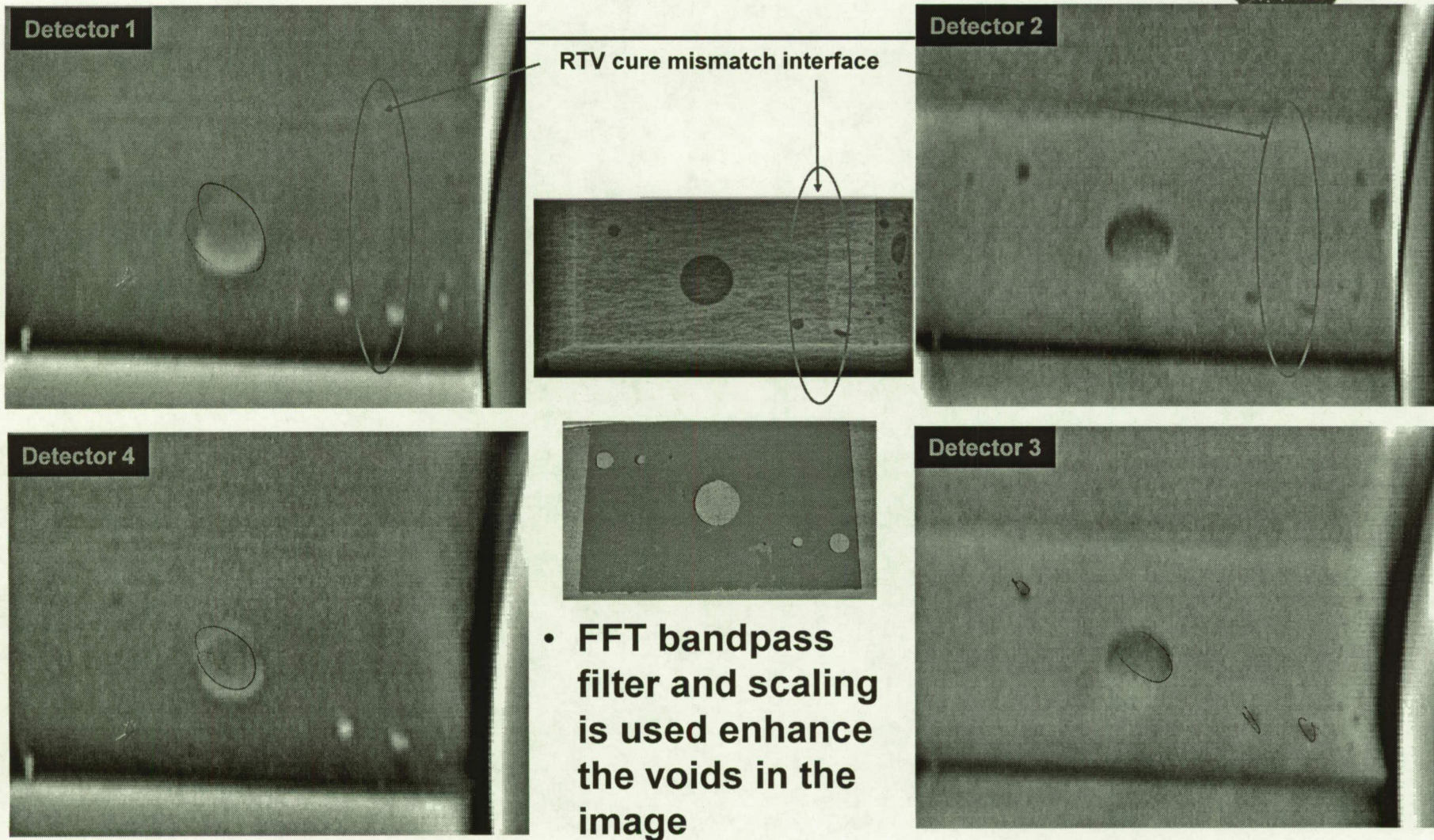


- The 1in, the partially filled 0.5in and the 0.25in holes can be clearly seen by each detector

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- The 0.25in hole on the near the TPS interface be seen by detector 4

Scan 23° Tilt, FFT Filter



Summary



- We developed data and a moisture model to verify ULA approach to estimating moisture levels (therefore fairing strength) at launch.
- We have demonstrated a method to perform 1 sided X-ray of the PICA heat shield RTV seams. This angled method is applicable to a wide variety of materials.
- We acquired test panels of structures of interest to Constellation to perform drying and other tests.